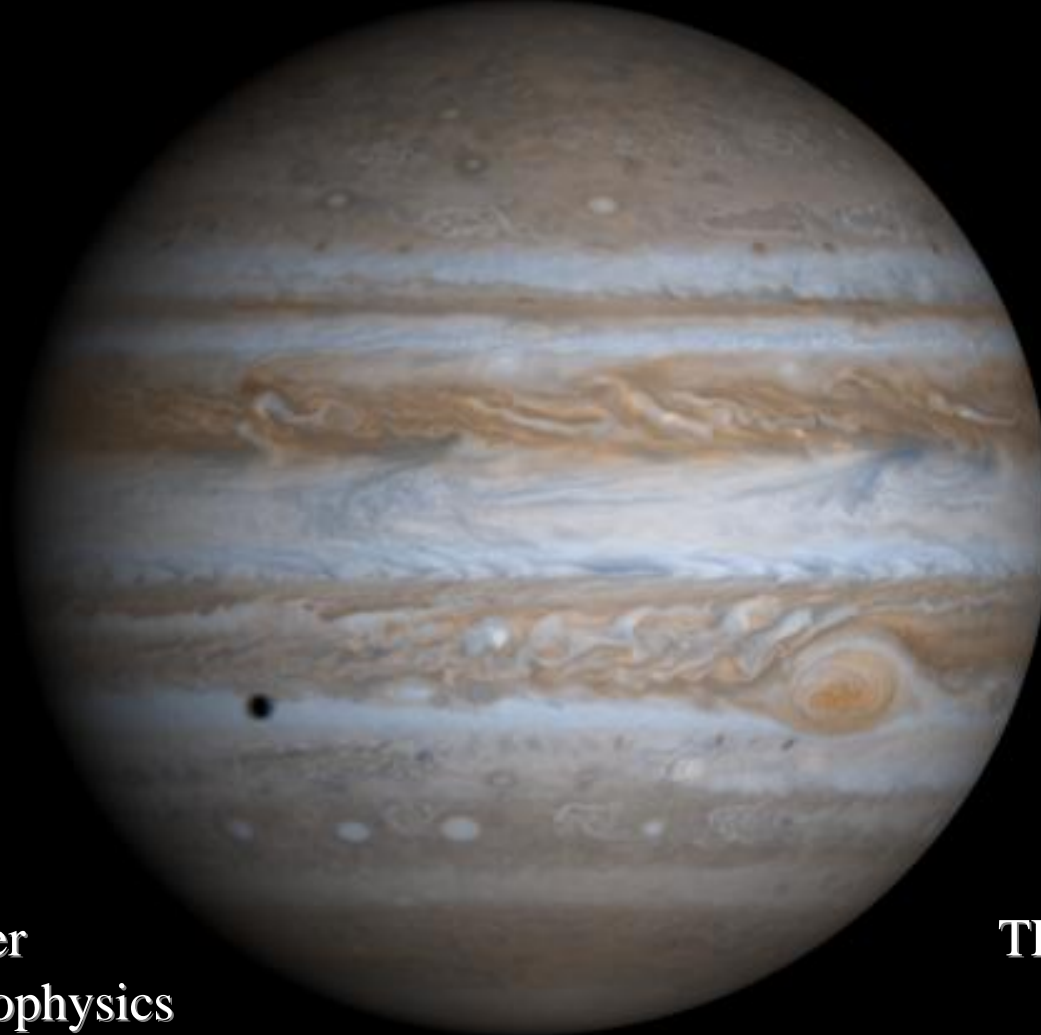


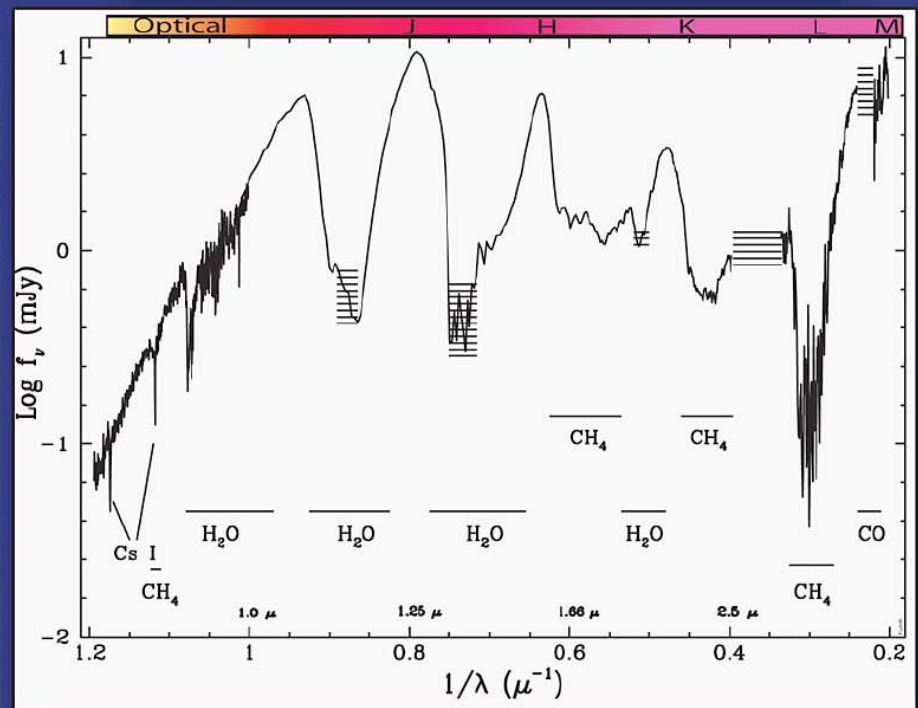
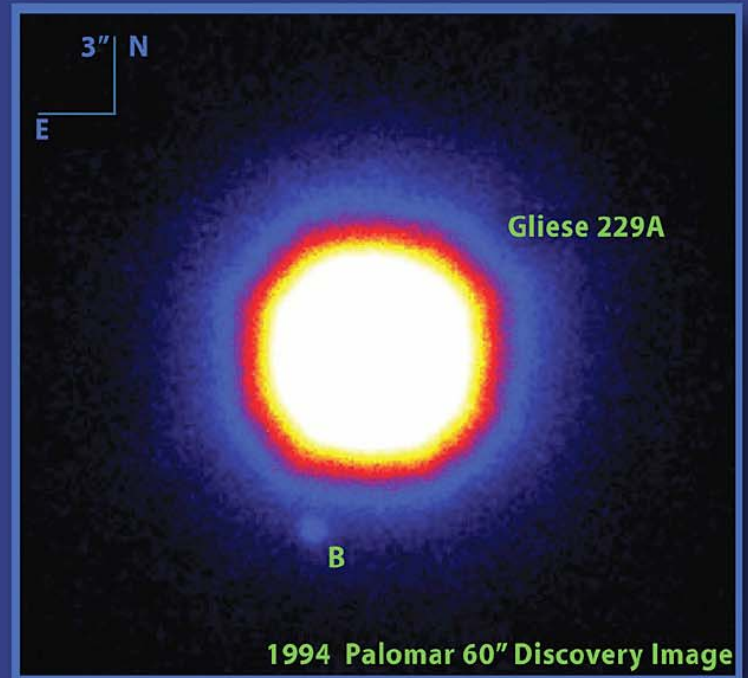
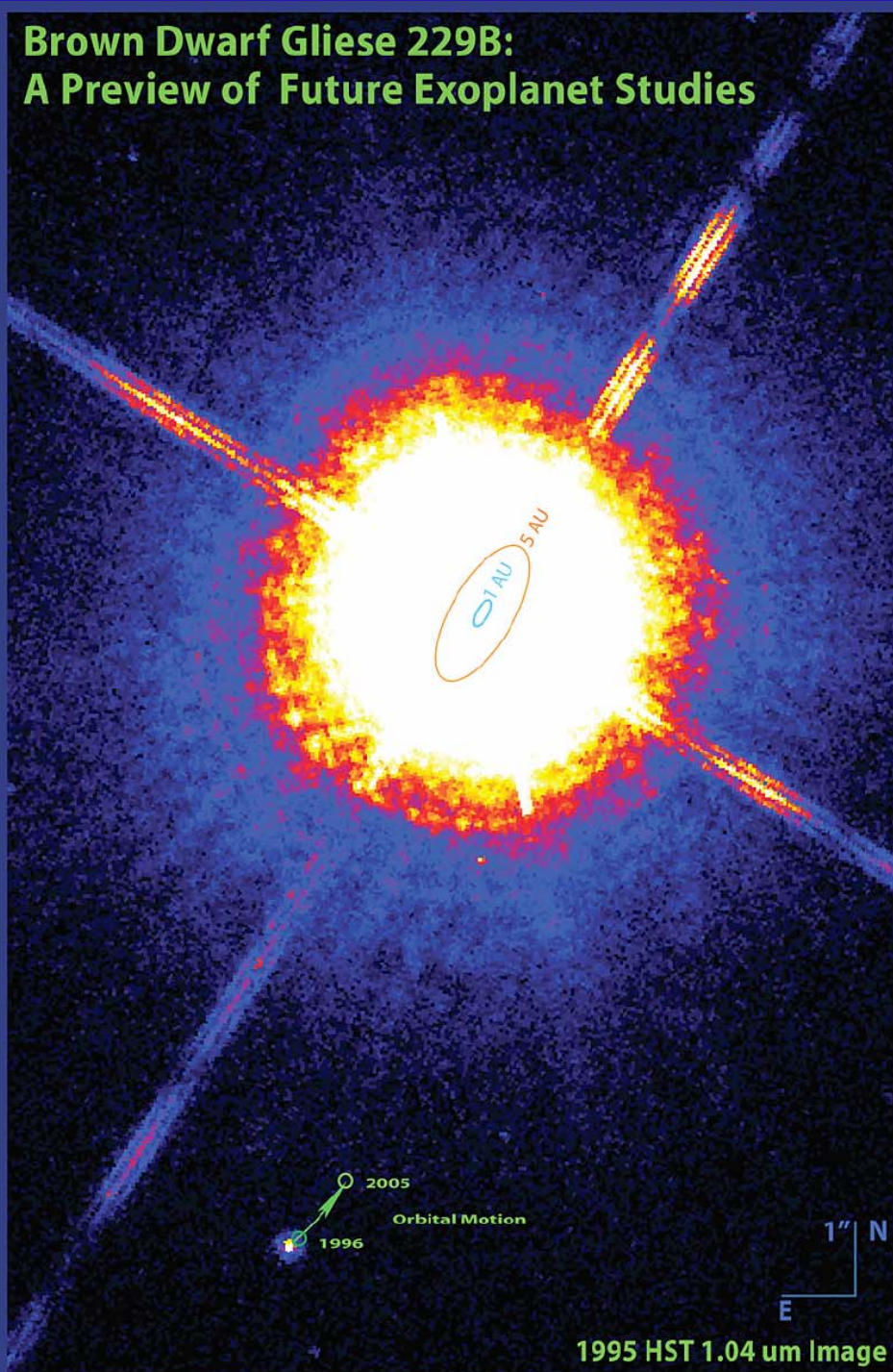
Brown Dwarf and Planet Science from Ground-Based Coronagraphs



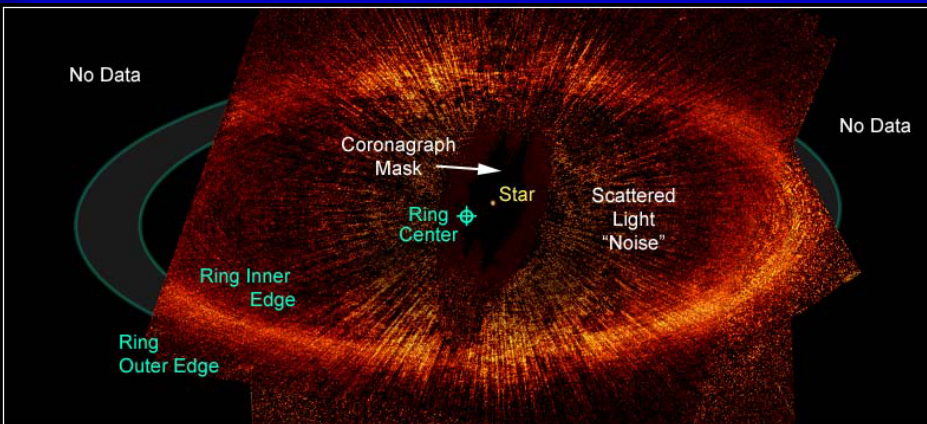
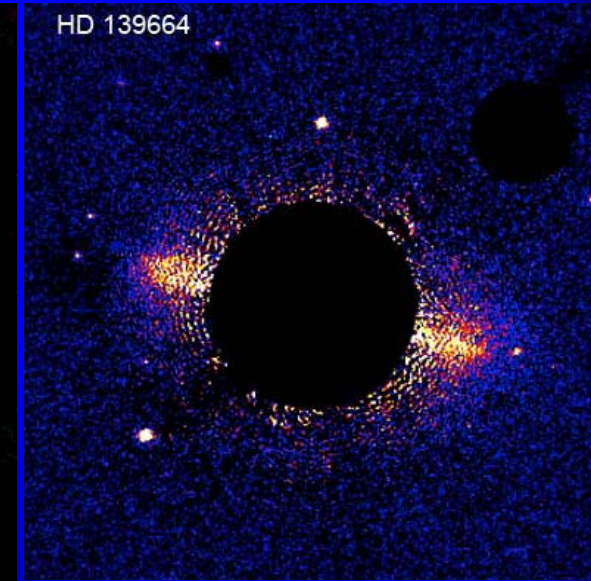
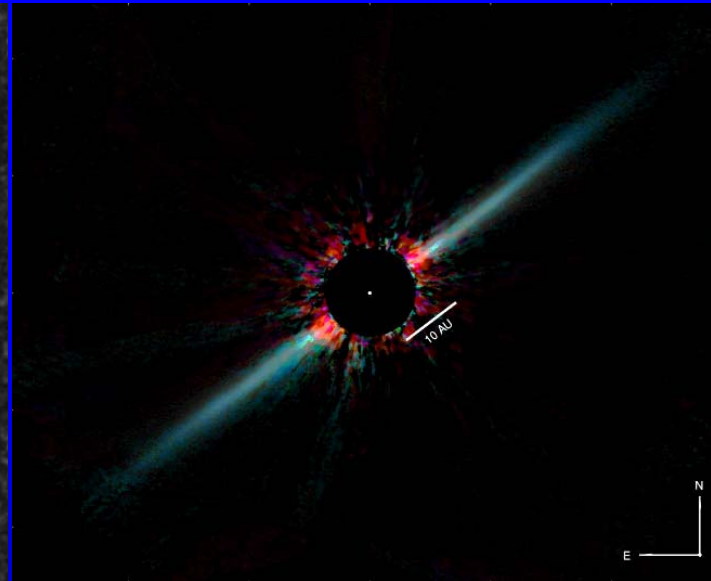
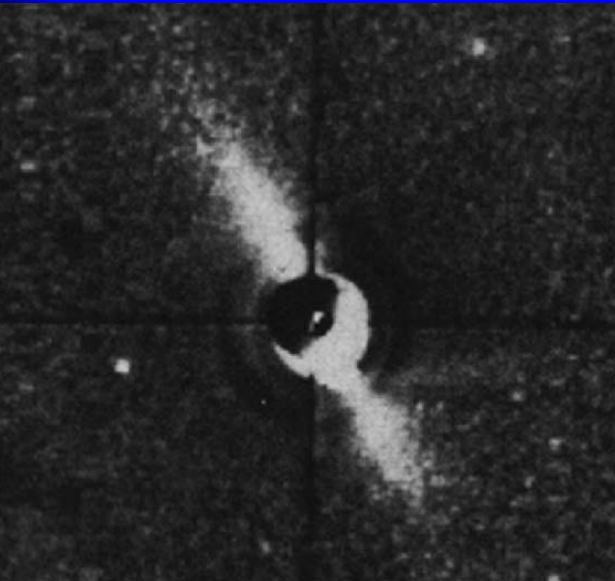
Ben R. Oppenheimer
Department of Astrophysics
American Museum of Natural History

TPF/Darwin Meeting
Cool Stars 14
November 8, 2006

Brown Dwarf Gliese 229B: A Preview of Future Exoplanet Studies

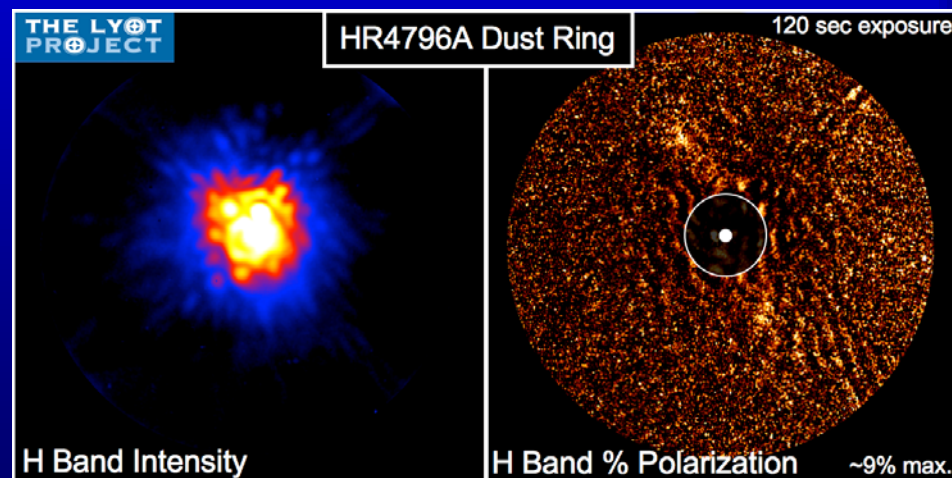


Circumstellar Disks



NASA, ESA, P. Kalas and J. Graham (University of California, Berkeley)
and M. Clavin (NASA/GSFC)

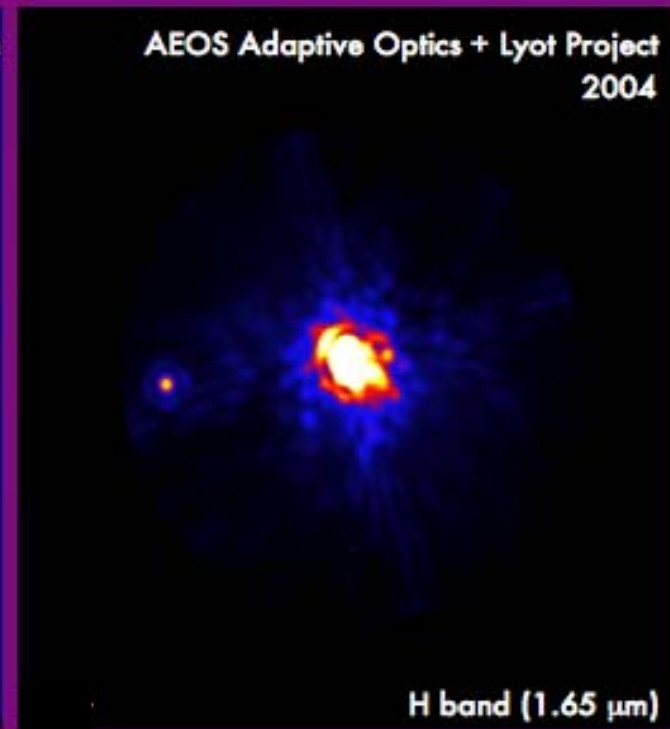
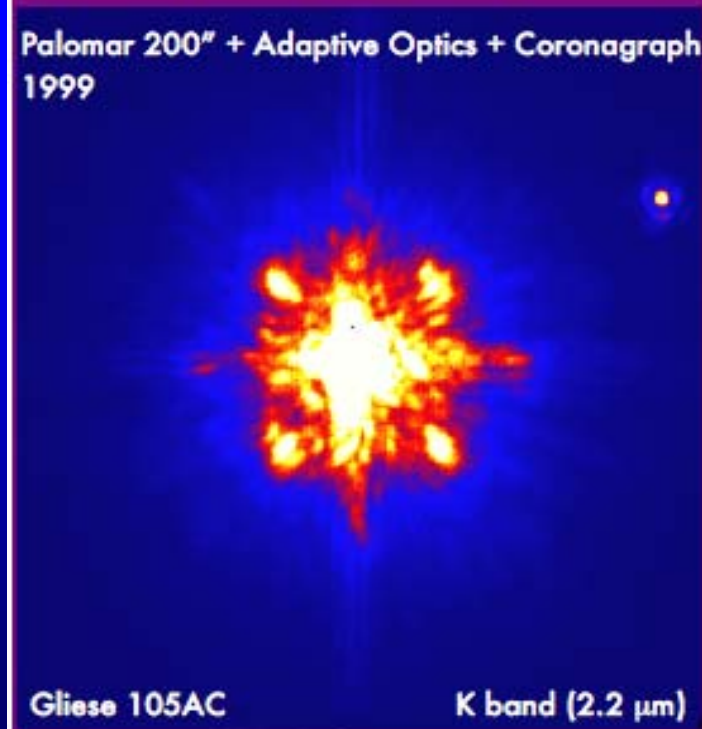
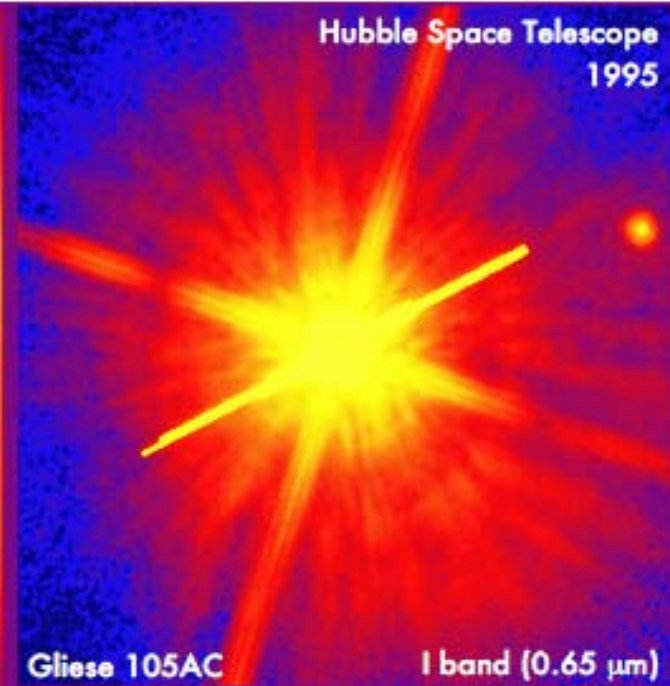
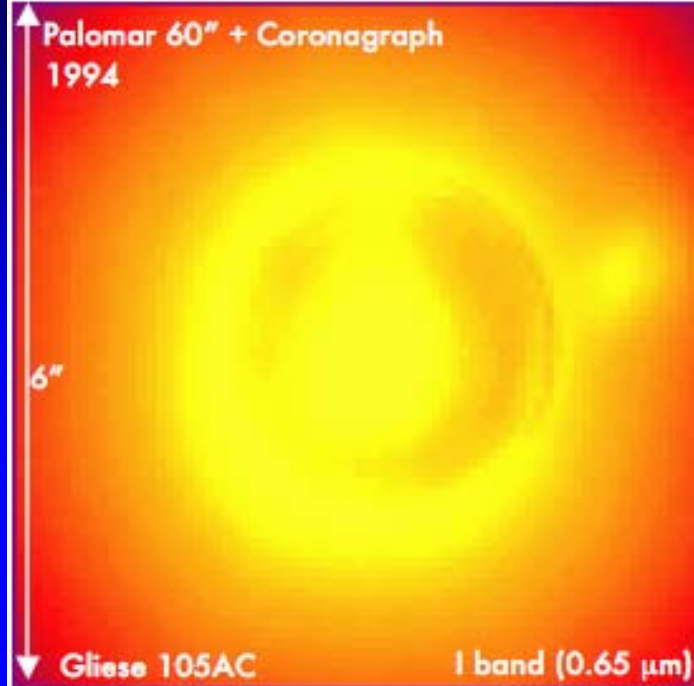
STScI-PRC05-10



10 Years of Starlight Suppression

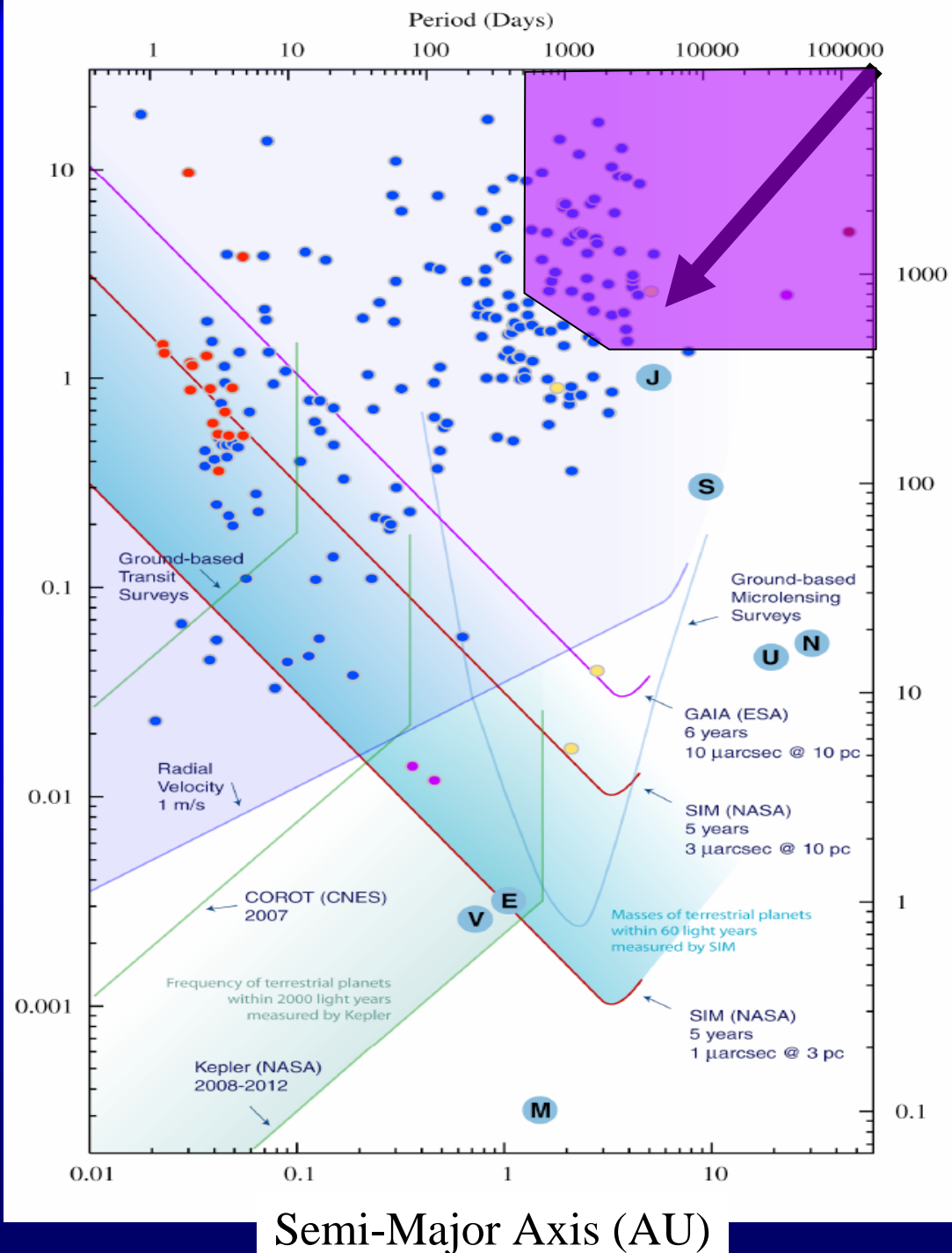
Qualitative
Comparison

This is hard!



The Known Planets

Companion Mass (M_J)



Companion Mass (M_E)

Semi-Major Axis (AU)

What Can We Expect From Ground-Based Experiments?

**The goal: understand planets in general
a comprehensive theory of planetary science**

Largely High mass or young objects for now

- Formation**
- Evolution**
- Range of Masses**
- Diversity**

**These require hundreds
of planet spectra**

Debris Disks and Exozodiacal Light

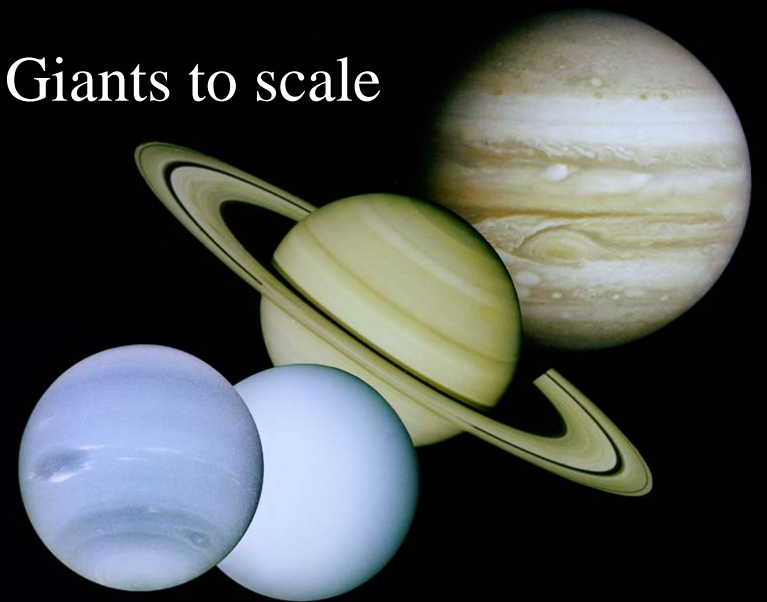
Brown Dwarfs

Planets are complex

Vogt-Russell Theorem: “mass and chemical composition are sufficient to determine the structure, evolution and outward appearance of a star completely”

Planets have a diversity possibly unmatched in astronomy, and the theorem does not apply

Giants to scale



Terrestrial Planets to scale

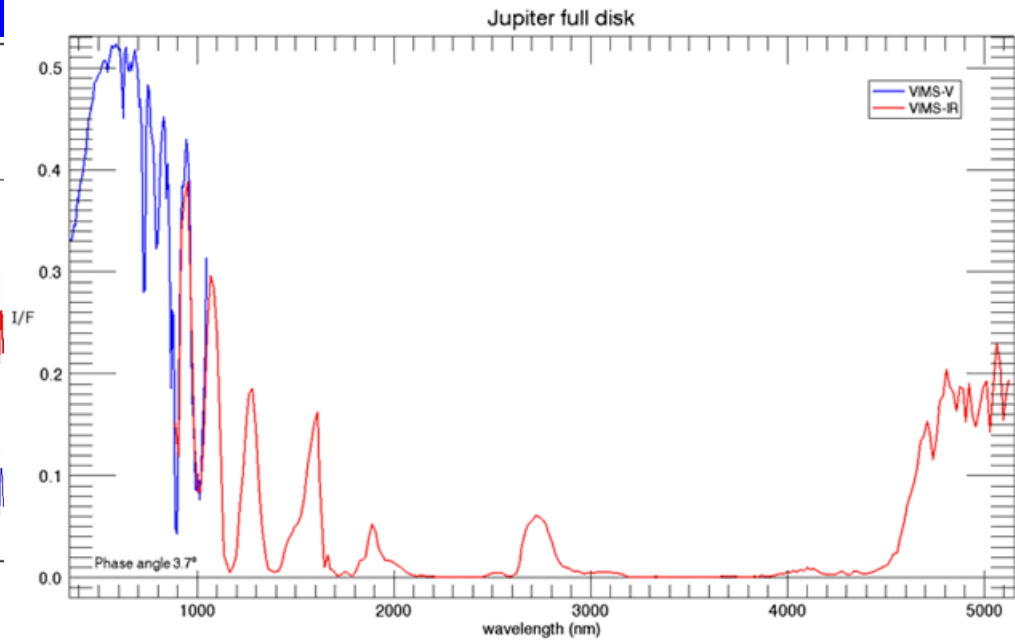
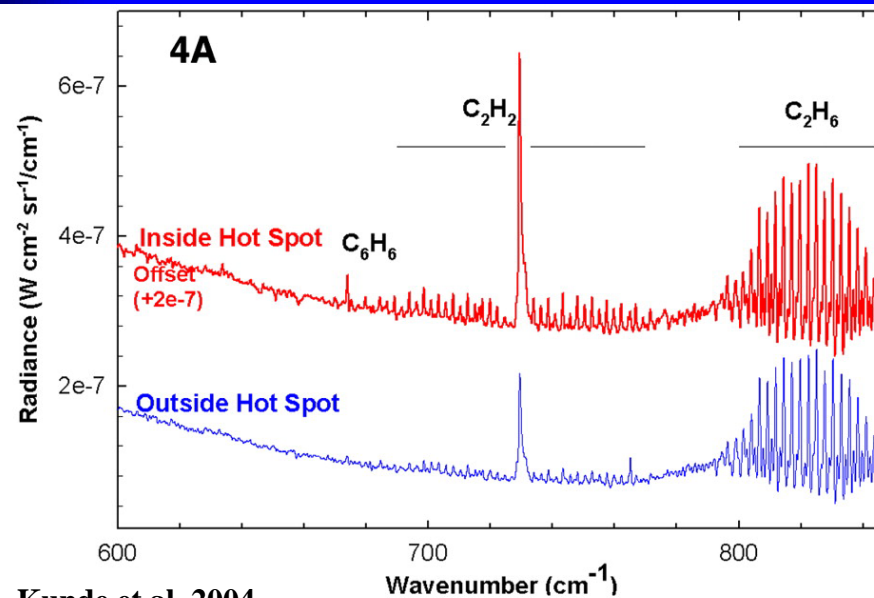


The onset of complexity perhaps begins in the brown dwarf mass range where age is needed as well.

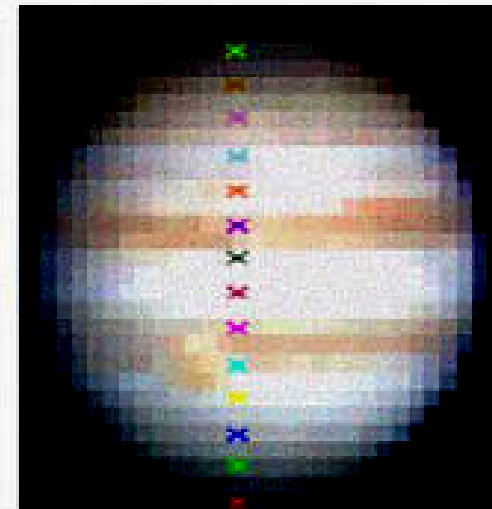
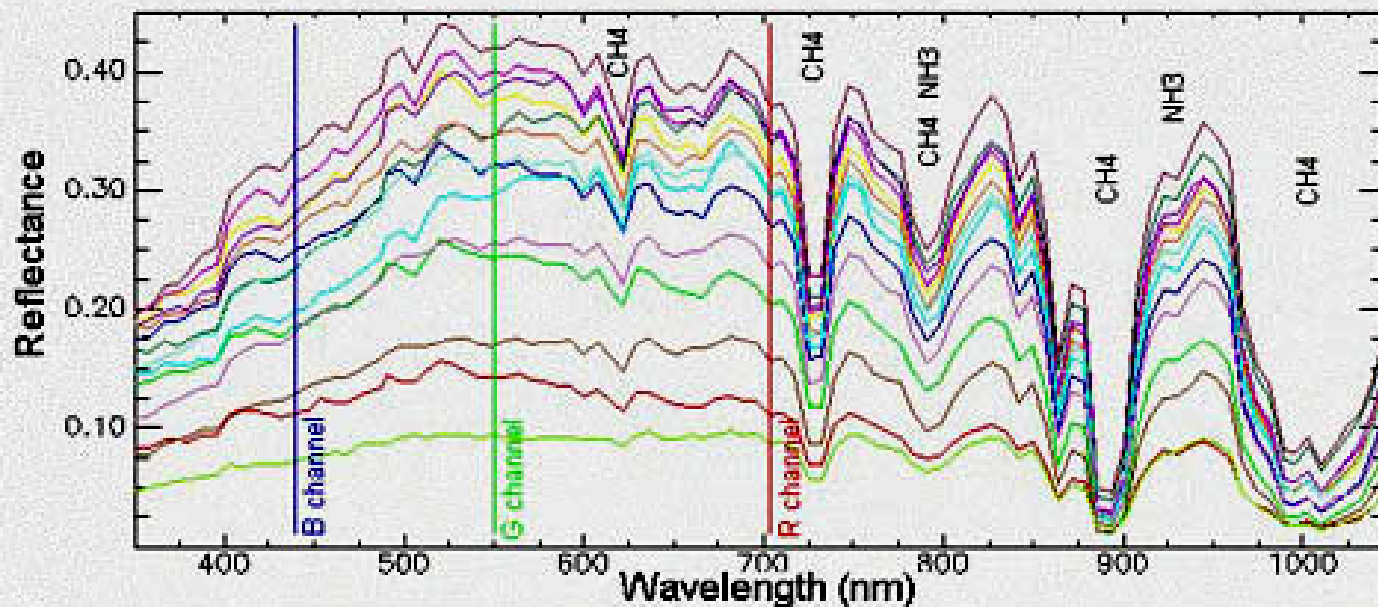
In coolest or lowest mass BDs, more complexity: The chemistry and colors are drastically affected by minor changes in composition

A few simple parameters are insufficient to determine a planet's salient features.

Jupiter: many different spectra, same object

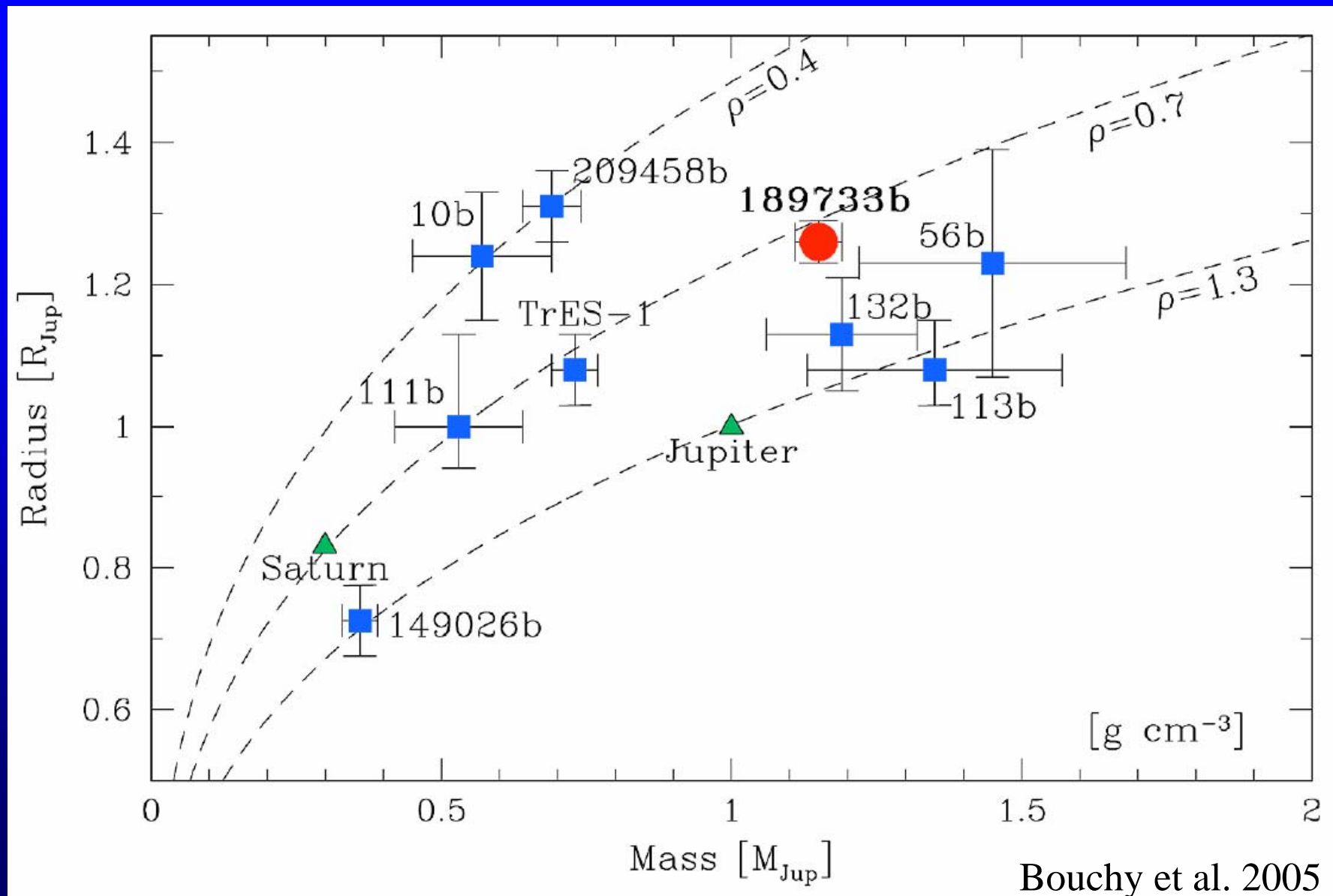


Kunde et al. 2004

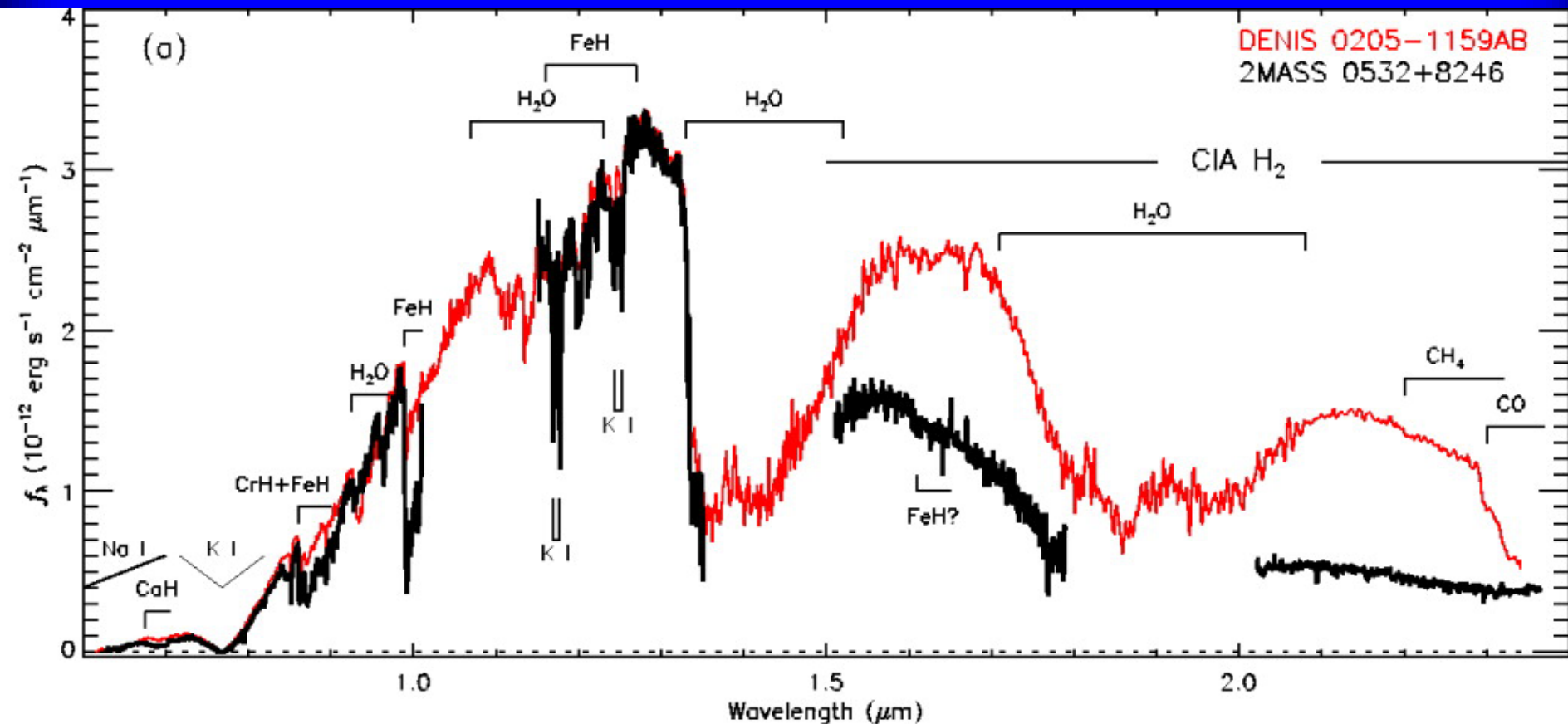


G. Filacchione (2001)

More Planet Diversity: Mass vs. Radius



BD Diversity: Metallicity



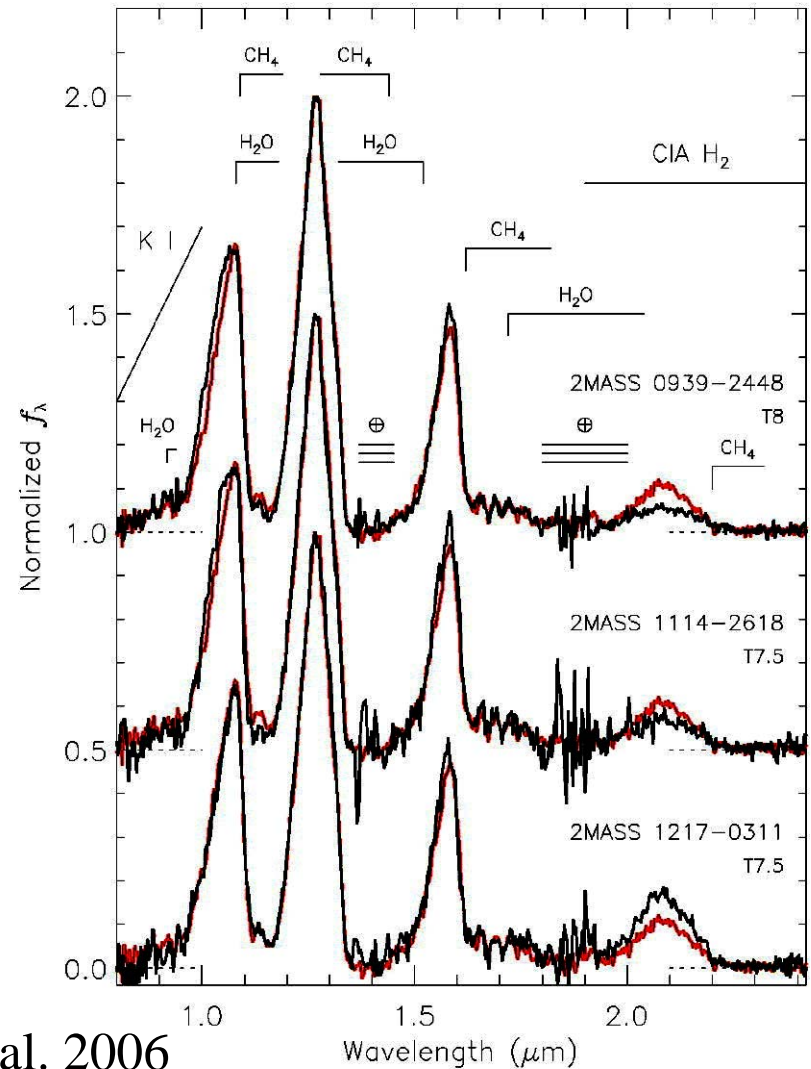
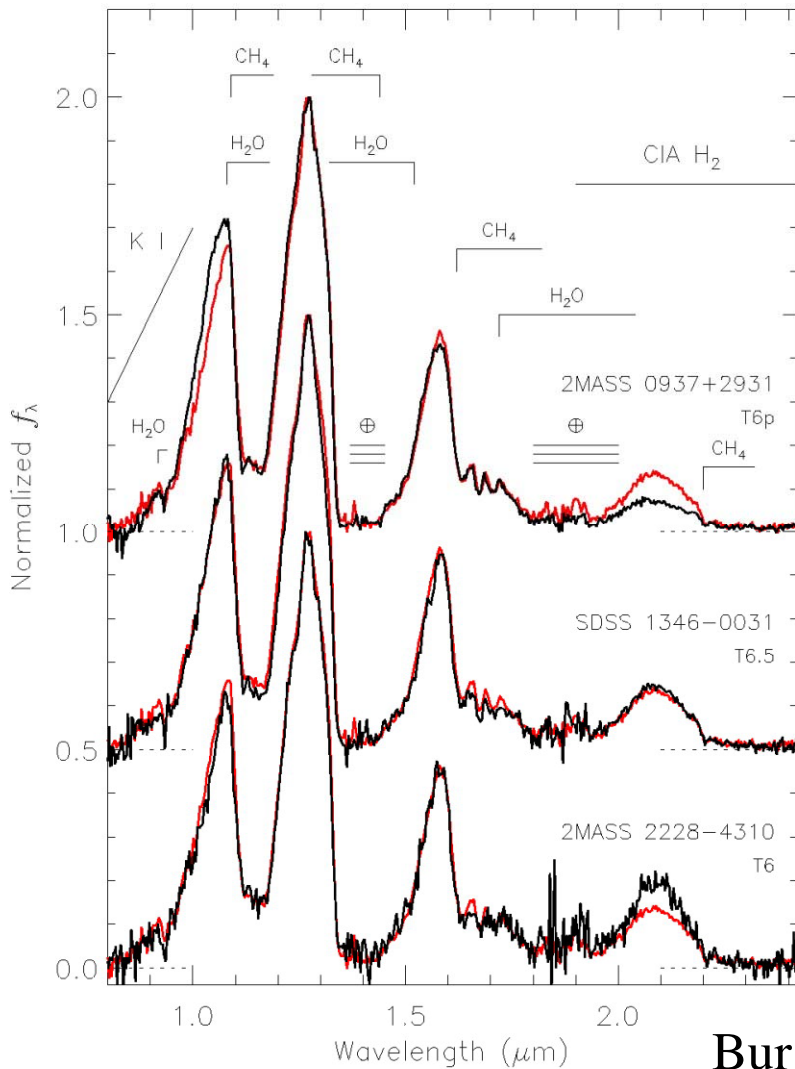
Red: L7

Black: L7 in optical, but near IR?! This is a very low metallicity L dwarf with Halo kinematics (Burgasser et al. 2003) H₂ CIA highly pronounced

BD Diversity: Gravity

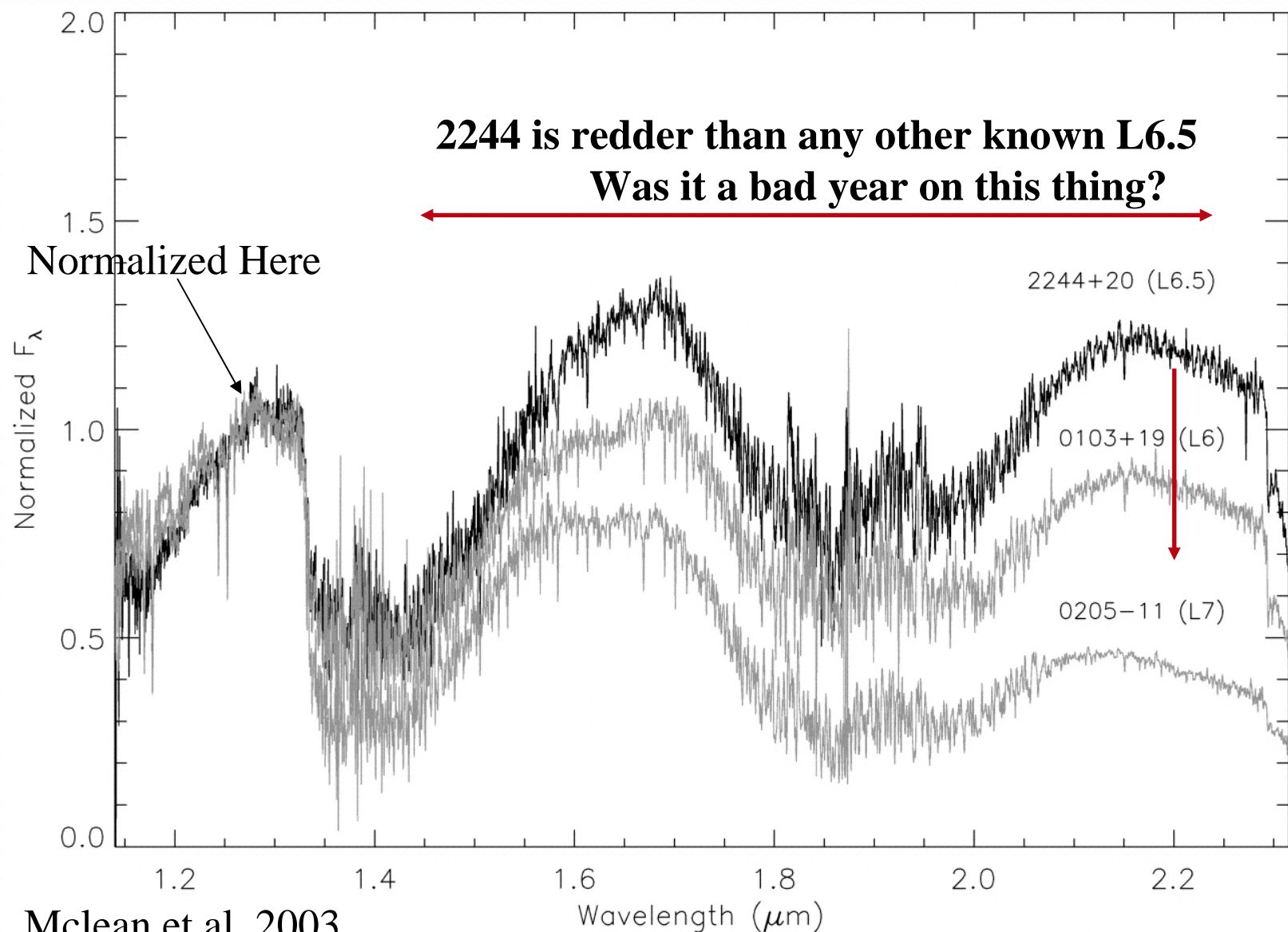
T6: Red = SDSS1624+0029

T7.5: Red = Gliese 570D

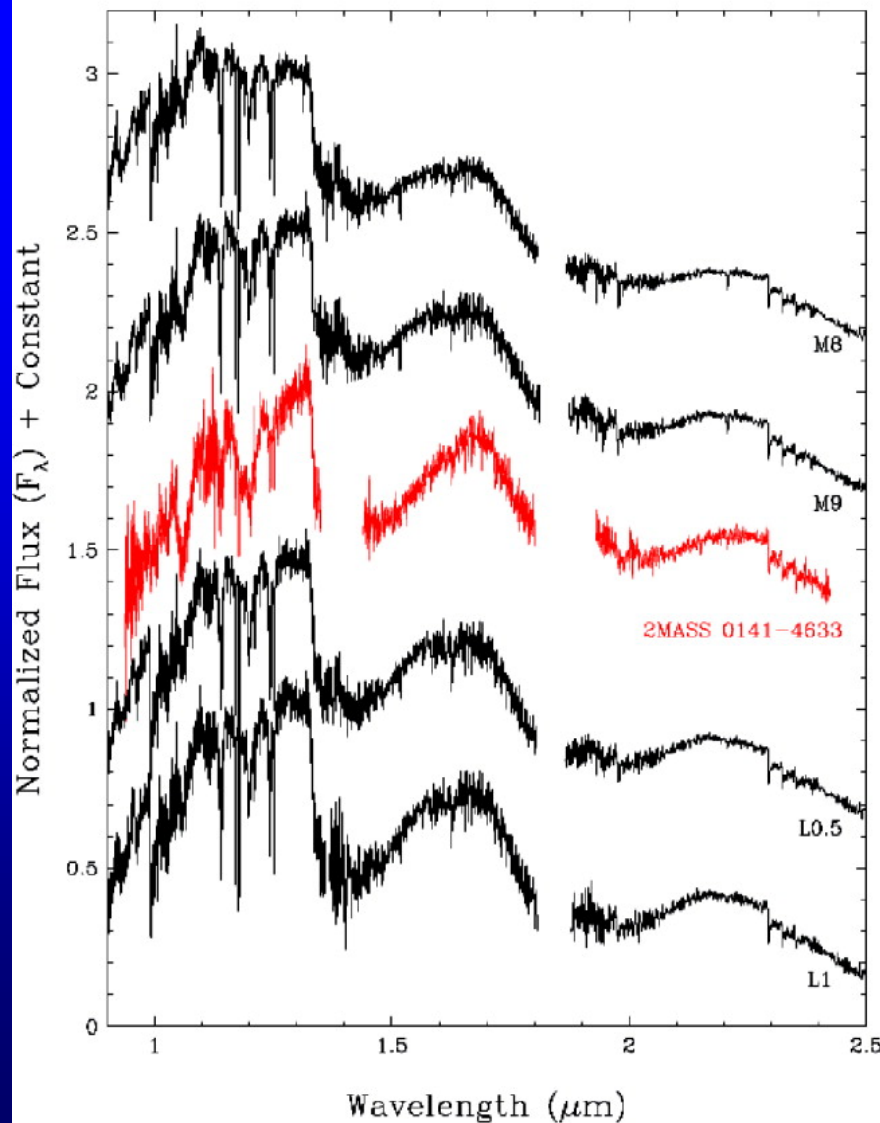


Burgasser et al. 2006

BD Diversity: Dust Content



BD Diversity: ??

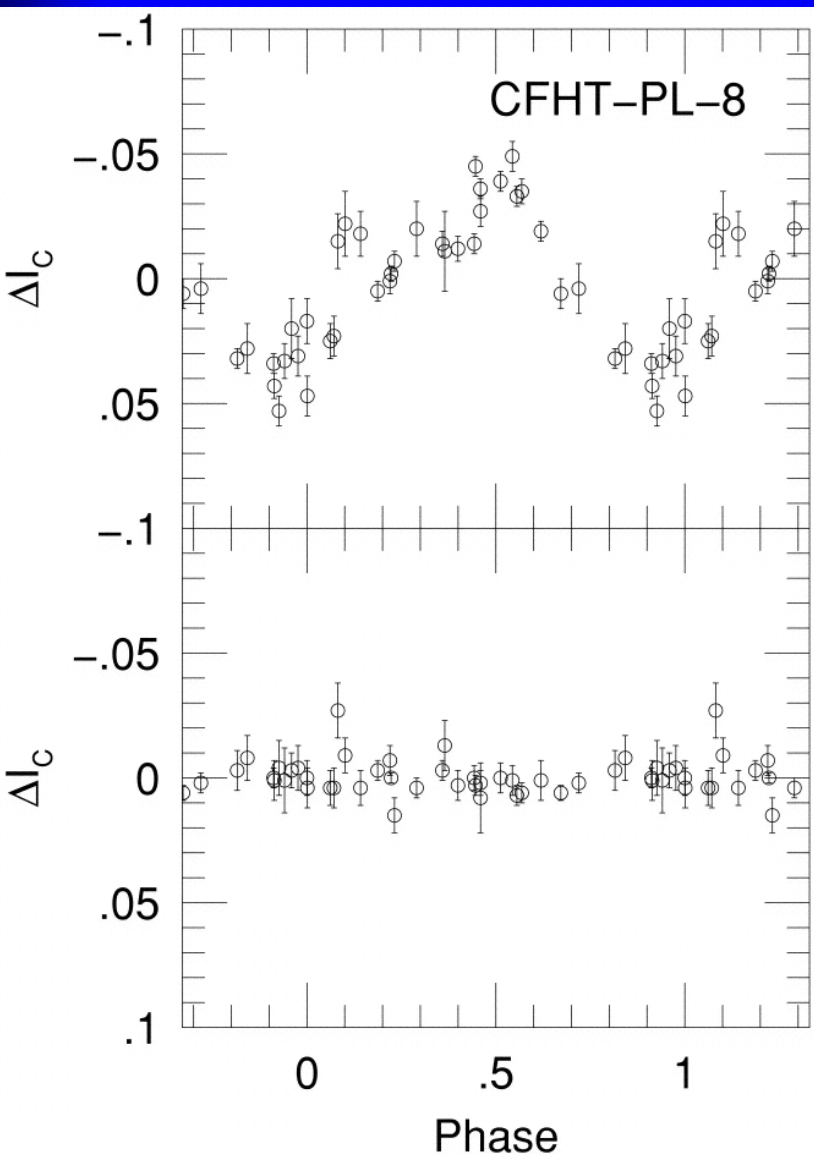


Kirkpatrick et al. 2006

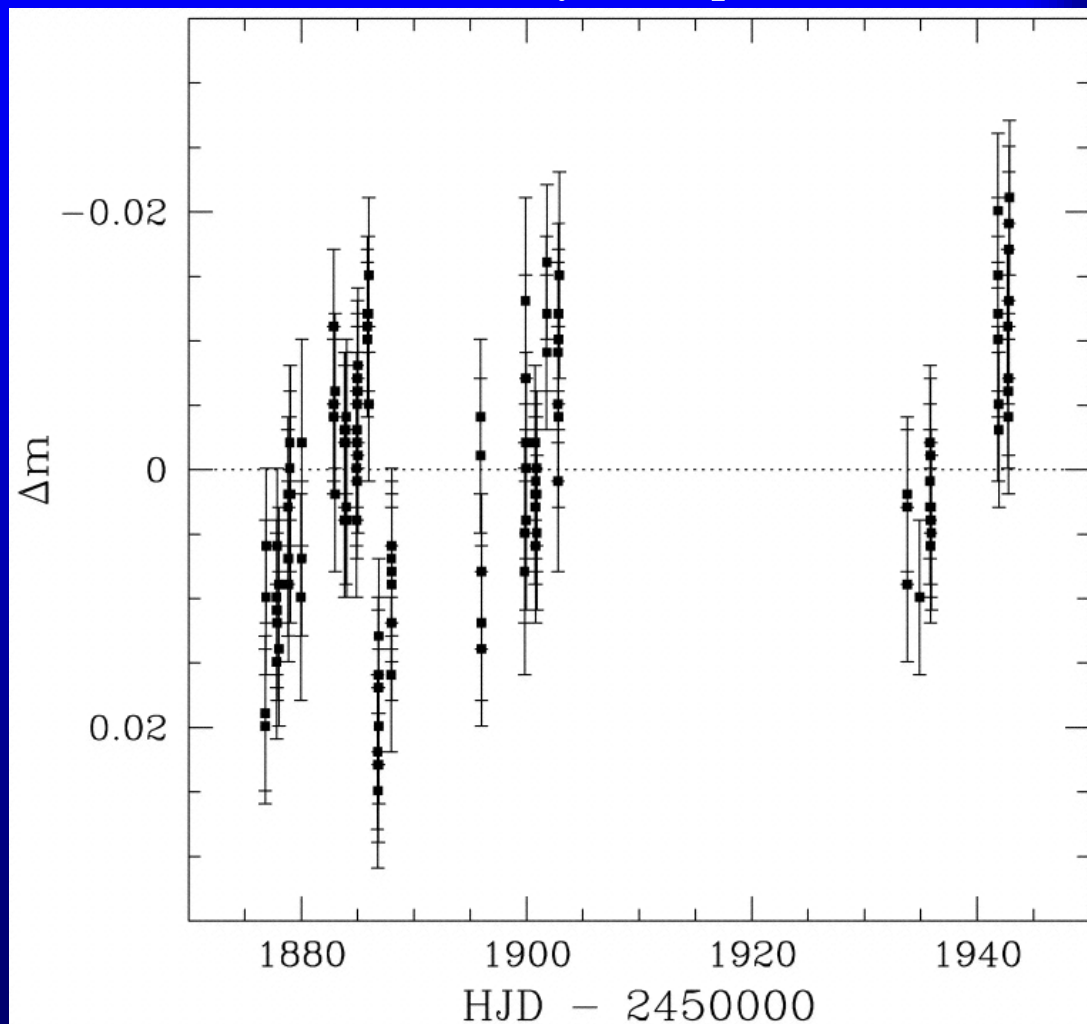
Photometric Variability

Observed in nearly every L dwarf for which good time series data exist

4.5 hours Periodic



Several days, not periodic



Brown Dwarfs are Critical to Exoplanetary Science

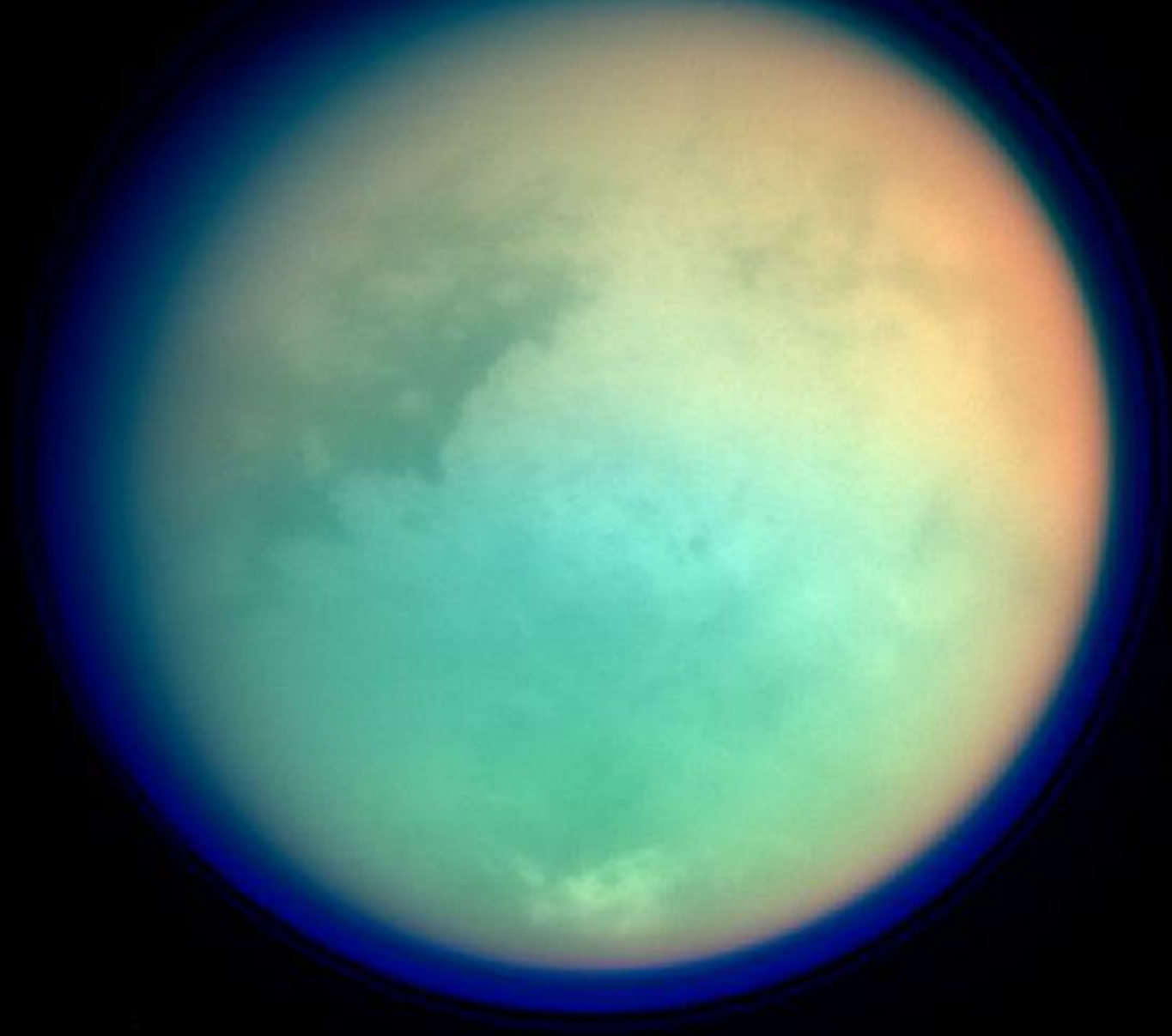
What if there is no Y spectral Class? What if we are really facing the problems that meteorology has in predicting the weather?

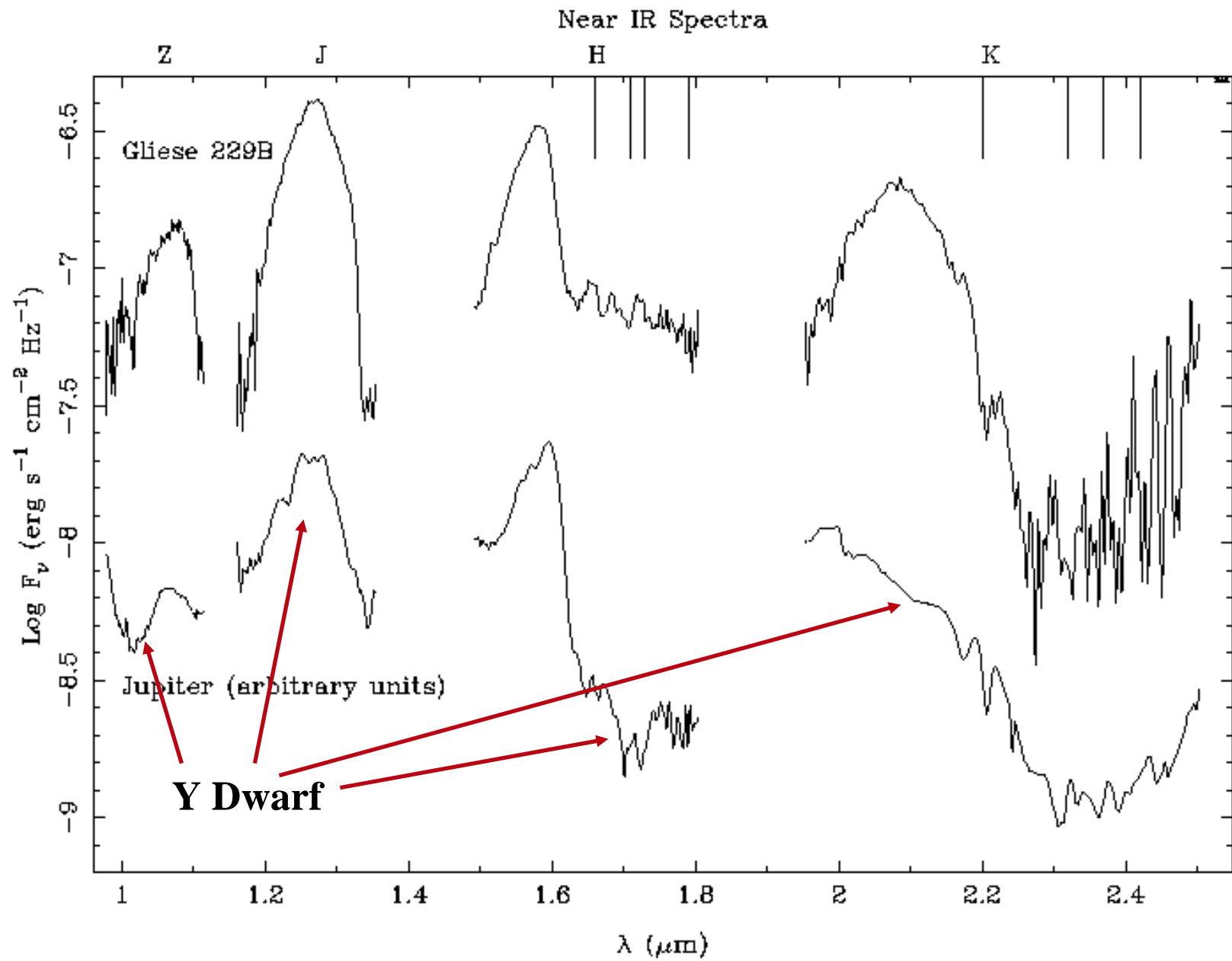
This is where ground based coronagraphy becomes critical

- **Hundreds of Brown dwarfs and high-mass or young exoplanets**
- **Parallaxes and dynamical masses**
- **Galactic dynamics of stars with solar systems and brown dwarfs**
(The importance of astrometry cannot be overstated)

If you don't believe me yet, just you watch!

**This object has a T6 spectrum, but is 94K and has a
mass of $0.022 M_E$**



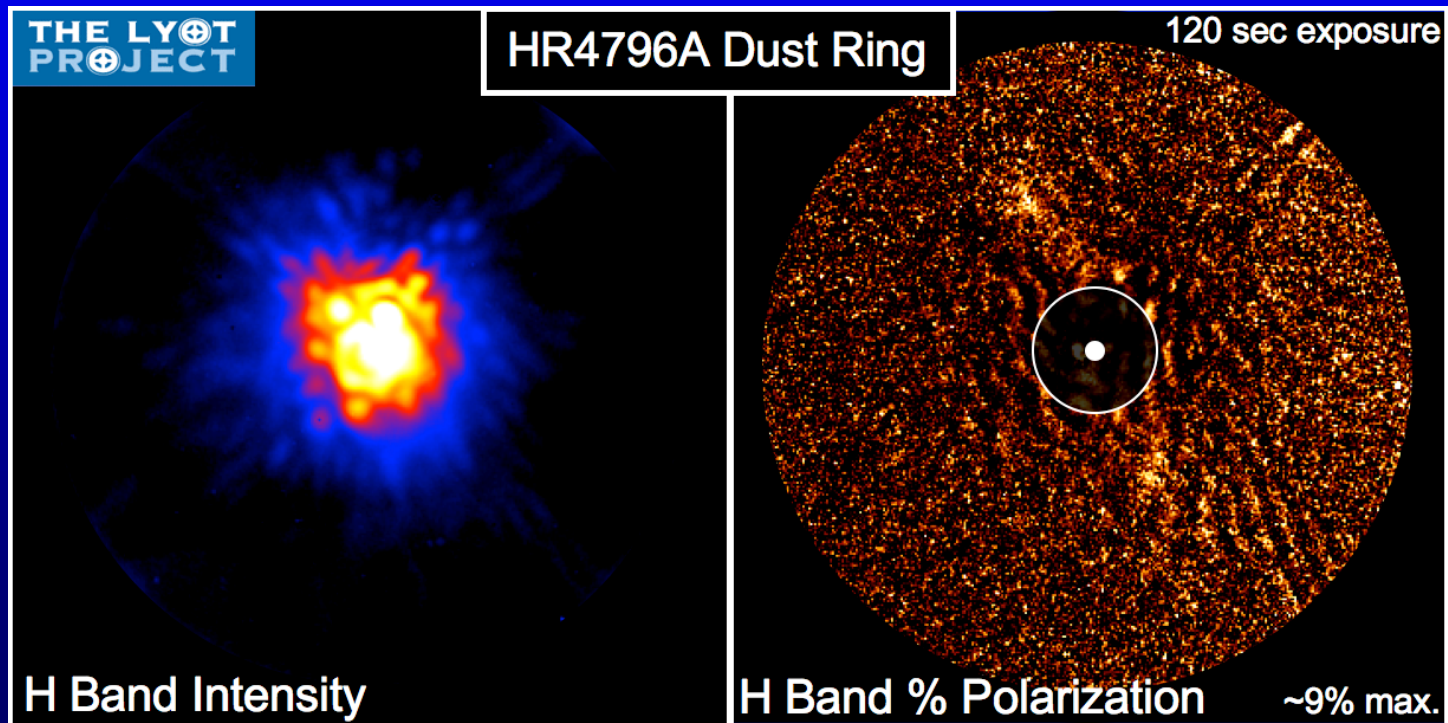


(Oppenheimer et al. 1995)

So What's the Point?

Only from the ground can we ensure

- Discovery of hundreds of objects
- Spectroscopy of hundreds of objects
- Time resolved observations
- Exhaustive studies of individual objects: eg polarimetry
- The understanding is hidden in the details



Cf Venus

Lyot Project Common Proper Motion Companion

H-Band 15 minute exposure

$10^{-4.0}$
~65 M_J
47 AU

H-Band
S ~ 80-90%

H-Band
15 minute exp.

Weird colors
(i, z, J, H, K)

Companionship
confirmed

A3V, $M_H = 1.39^m$, Companion: $M_H = 11.4$

5"

Oppenheimer et al. in prep.

Strange things are out there and people will argue: Let's see what the rest of this session has to offer!